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A FILM THERMOCOUPLE WITH A PLATINUM ELECTRODE FOR THERMOMETRY OF GAS TURBINE ENGINE BLADES

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16. Abstract

An investigation is made of platinum used for film thermoelectrodes. A description is given of the tests, and it is concluded that a platinum film thermoelectrode has adequate stability for technical applications.

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A FILM THERMOCOUPLE WITH A PLATINUM ELECTRODE FOR THERMOMETRY OF GAS TURBINE ENGINE BLADES

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A great deal of attention is given to the problem of measuring the temperatures of the working blades in tests and when adjusting a gas turbine engine, since the thermal state of the blades greatly determines the reliability and power of the engine. At the present time, to measure the temperature of the working blade surface, use is made of wire thermocouples insulated against high temperatures, either applied along the blade surface and covered with a casing of foil, welded by means of contact weldings to the blade surface, or laid in channels specially cut into the blade and then covered with foil. /31*

However, the channels greatly decrease the strength of small blades, and the dimensions of the outer section, which are commensurate with the dimensions of the blade cross section and the interblade channel, lead to great methodical errors /32
due to distortion of the temperature field and the flow around the blade. The errors increase even more when measurements are made during the transitional operational regimes of the engine, when the thermal inertia of the wire thermocouples in the form described above begins to have an influence.

* Numbers in the margin indicate pagination of original foreign text.

To decrease the methodical errors, a thermocouple was developed which is formed by a film thermoelectrode and the material of the component [1,2]. The film thermoelectrode is placed on the surface of a component made of an electrically conducting material, and with the exception of the welding region, is entirely separated from it by a layer of an electrical insulator - backing. The thermal EMF which is produced at the welding point is removed from the film and the component material by means of compensation wires which are attached at the most suitable section of the component having the minimum temperatures and gradients over the surface. Films of nickel obtained by precipitation in a vacuum are used as the film thermoelectrodes [1]. This type of thermocouple has stable properties in a temperature range up to 650-700° C with long use and 1000° C with short use (2, 5-3 hours).

It was of interest to obtain film thermoelectrodes which are more resistant to temperature, for example, platinum. Platinum is acknowledged to be a highly stable thermoelectrode material. It has a high temperature range, and as will be shown below, is very economical and simple to produce in the form of a film.

Brazing is used to obtain electroconductive metallic films made of platinum. These methods consist of the thermal reduction of platinum from composite compounds of chloroplatinic acid H_2PtCl_6 and of the subsequent brazing of the reduced metallic film on the material of the insulator-backing or the metal of the component. The working solution (paste) is applied on the surface in the form of a film having a specific geometry by means of pens or small brushes [3, 4, 5].

The basic components of the paste are as follows: a) components containing platinum — usually chloroplatinic acid;

b) components forming a film — vegetable oils (lavender oil, oil of cloves, linseed oil), colloid oil, glycerine, etc.; and c) solvents — methyl alcohol, ethyl alcohol, acetone, turpentine, etc.; d) thickening agents. These elements are introduced to decrease the viscosity of the solution film during high temperature heating, particularly natural resins such as rosin and copal.

As has been shown, compounds with film-forming oils, which were recommended in [3, 4, 5], do not produce a clear picture of the film on a surface having composite form and curvature, due to significant viscosity.

Compounds with an addition of boric acid, which were recommended in [5], do not provide the necessary homogeneity over the length.

Good results were obtained with the following working solution (percent by weight): /33

Chloroplatinic acid — 12-13%;
Nitrocellulose (combustible movie film) - 4-6%;
Methyl alcohol - in an amount which brings the total weight of the ingredients up to 100%.

The use of nitrocellulose makes it possible to eliminate the spreading of the working solution and to accelerate the process of heat treatment.

Before the application, the surface is purified and degreased in the regular way. To improve the quality of combining the platinum film with the metal, it is recommended that the part be heated up to 60-65° C when applying the working solution. The application is performed by means of a glass or polyvinyl chloride pen with an opening diameter of 0.5 - 0.8 mm.

After the working solution film is applied, drying is carried out for 1.5 - 2 hours with a gradual increase in the temperature up to 150-160° C. The dried film has a dark red color or is a brilliant white.

The sample with the film is heated further in a furnace at a heating rate of about 4° per minute. During the heating, the organic portion of the solution is burned up, and the platinum is reduced to a metal (500-520° C). After a mirror of metallic platinum appears, the heating rate is increased to 8-12° C per minute. The heating is carried out to temperatures of 750-1100° C as a function of the backing form and the material of the parts.

The film obtained has good resistance (approximately 10-15 ohm per square). Subsequent applications make it possible to reduce the resistance to 0.1 - 0.2 ohm per square, and also to increase the stability and the thermal resistance coefficient (TRC) of the film. The value of the TRC for films of three- and four-fold applications is $(3.37\text{-}3.41)\cdot 10^{-3}$ 1/deg. This approximately corresponds to the data given in [6]. The TRC of a film with one application is much less (about $2.5\cdot 10^{-3}$ 1/deg) and does not have adequate reproducibility.

Stabilizing combustion of film thermoelectrodes is carried out for two hours at temperatures which are approximately 100° C lower than the brazing temperature.

The basic requirements imposed on the platinum films obtained were that they have thermoelectric stability in the working range of temperatures, have reproducible characteristics for films of different parts, and have uniform thermoelectric properties over the length of the film.

To determine the thermoelectric stability of a platinum film thermoelectrode obtained by brazing according to the method given above, a method was selected [7] which can be generally used for wire thermoelectrodes. It consists of recording and /34
analyzing the constancy of the EMF of the thermoelectrode being studied with respect to a group of normal platinum thermoelectrodes. (GNPT) after annealing at different temperatures.

The platinum branch of a sample platinum rhodium-platinum II discharge thermocouple was selected as the standard for comparison in preliminary studies. This thermocouple was made of PL-3 wire according to GOST 8588-57 with a temperature coefficient of $\alpha_0^{100} = 3.920 \cdot 10^{-3}$ 1/deg.

A layer of the backing-insulator was applied on samples made of steel KH 18N9T with a dimension of 180x8x2.5 mm. Then the platinum film thermoelectrode being studied in the form of a band with a width of 1.5 mm and a length of 160 mm was applied. There were four applications, and the widths of the films determined by the MIM-7 microscope with a magnification of 100 were 1-2 μm.

The length of the sample was selected so that it was possible to place a thermostat at the place where the copper discharge wires coming from the furnace were attached to the film thermoelectrode and the metal of the sample. This was done by a special refrigeration unit, which was attached to the sample and was rotated between the furnace and an ice bath.

In the immediate vicinity of the junction, the junction of the wire sample platinum rhodium-platinum thermocouple, which was in contact with the film thermoelectrode, was welded on. To reduce the errors caused by a nonuniform temperature field in the region where the sample thermocouple was attached and where the heat was removed along the thermoelectrode, the end of the sample with the junction was placed in a ceramic tube with a powder of aluminum oxide.

Calibration was performed in a special tubular furnace with the sample immersed at a constant depth. Thus there was a temperature gradient of no more than 0.2 deg/mm over the length of the sample at 40 mm, including the region of the junction.

During the calibration, in addition to the signal of the sample thermocouple and the thermal EMF of the film thermoelectrode with respect to the platinum branch of the sample thermocouple, the thermal EMF of the thermocouple for the sample material-film platinum thermoelectrode was also measured.

A potentiometer R-306 was used as the measuring device, and the signals to this device were supplied by means of a switch.

The stability of the platinum film thermoelectrodes under the influence of isochronous annealing was also studied. The thermoelectrodes on the samples, whose entire length was placed in the furnace, were subjected to annealing at temperatures of 800, 900 and 1000° C for three hours. The stability was determined by comparing the calibrated characteristics which were determined after each isochronous annealing. To reduce the number of experiments, the calibrated characteristics were determined and compared between 0 - 600° C. /35

The criterion for the stability of the characteristics of the platinum film thermoelectrodes was the relative selected dispersion δ determined according to the formula

$$\delta = \frac{1}{\sqrt{n}} \cdot \frac{1}{k} \sum_{j=1}^{k} \sqrt{\sum_{i=1}^{n} \left[\frac{E_i(t_j, 0) - \bar{E}_i(t_j, 0)}{E_i(t_j, 0)} \right]^2},$$

where $E_i(t_j, 0)$ - is the thermal EMF of the platinum film thermoelectrode with respect to the platinum branch at a temperature t_i for the ith annealing $(i = 1, 2, \ldots, n)$;

$\bar{E}_i(t_j, 0)$ - mathematical expectation of the similar thermal EMF for all n annealings;

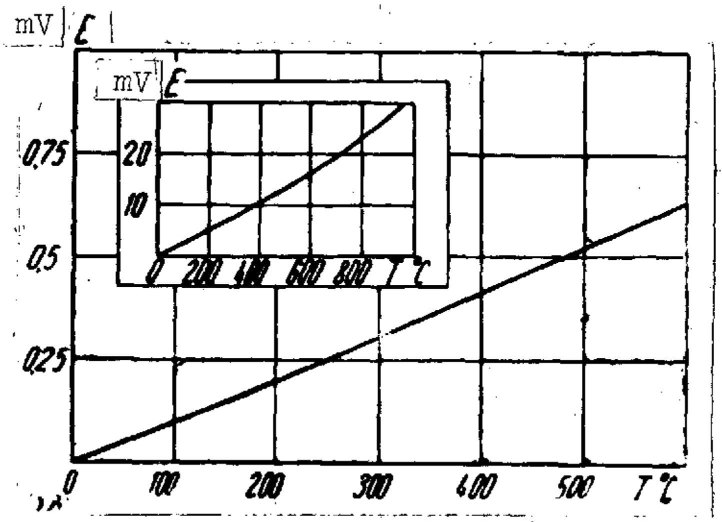
t_i - temperature between 0 - 600° C at which the thermal EMF was measured $(j = 1, 2, \ldots, k)$.

As has been shown, the values of δ for the film platinum thermoelectrodes which we studied changed between 0.6-1.7%, which is a characteristic of absolute instability as a result of isochronous annealings (with respect to the normal platinum thermoelectrodes).

If the value of the thermal EMF of a real film thermocouple (for example, with the alloy ZHS6-K as is shown in the figure) is referred to the instability obtained, the values of δ will be greatly reduced and will be between 0.03-0.08%.

The reproducibility of the characteristics of the platinum film thermoelectrodes of the different parts, obtained by the method described above, is characterized by a maximum scatter of ± 0.08 mV (at a temperature of 600° C).

The thermoelectric nonuniformity of the platinum film thermoelectrodes, studied by the method of local heating, did



Averaged dependence of the thermal electromotive force of a platinum film thermoelectrode with respect to the platinum branch of the standard thermocouple:

Above: Thermal EMF of the platinum film thermoelectrode-ZHS6-K alloy pair.

not exceed 10 μV at a length of 120 mm. In our opinion, this may be explained by the high chemical uniformity of the solution used for applying the films. /36

Thus, the studies performed indicate that a platinum film thermoelectrode has adequate stability for technical applications, as well as reproducibility and uniformity over the length of the thermoelectric properties at temperatures up to 1000° C. In particular, it may be used as the film thermoelectrode of semi-synthetic surface thermocouples [1, 2].

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